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Meat Science 65 (2003) 1107–1115

MEAT SCIENCE

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Prediction of color, texture, and sensory characteristics of beef steaks by visible and near infrared reflectance spectroscopy. A feasibility study☆

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Received 13 September 2002; received in revised form 27 November 2002; accepted 27 November 2002

Abstract

Color, instrumental texture, and sensory attributes of steaks from 24 beef carcasses at 2, 4, 8, 14, and 21 days post mortem were predicted by visible/near infrared (visible/NIR) reflectance spectroscopy in 400–1080 nm region. Predicting the Hunter *a*, *b*, and *E** yielded the coefficient of determination (R^2) in calibration to be 0.78–0.90, and R^2 was between 0.49 and 0.55 for tenderness, Hunter *L*, sensory chewiness and juiciness. The prediction R^2 for tenderness was in the range of 0.22–0.72 when the samples were segregated according to the aging days. Based on partial least square (PLS) model predicted tenderness, beef samples were classified into tender and tough classes with a correct classification of 83%. Soft independent modeling of class analogy of principal component analysis (SIMCA/PCA) model of measured tenderness showed great promise in the classification of tender and tough meats with over 96% success.
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Keywords: Visible/NIR spectroscopy; Beef meat; Tenderness; Color and sensory properties; Classification

1. Introduction

The characteristics of raw meats are influenced greatly by a variety of factors, for example, animal (breed, sex, age), environmental (feeding, transporting and slaughtering condition), and processing (storing time/temperature condition). During the aging, beef muscles undergo several changes that can affect their quality (Kinsman, Kotula, & Breidemstein, 1994; Lawrie, 1985; Price & Schweigert, 1987). These changes are reflected in many characteristics such as color, tenderness, flavor, and juiciness. One of the greatest challenges in the meat industry is to obtain reliable information about meat quality during post-mortem along the production process, ultimately providing guaranteed quality of beef products for the consumers.

Existing techniques in meat quality assessment, either instrumental (for example, Warner-Bratzler shear force measurement and Hunter color measurement) or sensory evaluation can provide reliable information about meat quality (Bouton & Harris, 1972; Huff & Parrish, 1993; Lyon & Lyon, 1991; Shackelford et al. 1991; Shackelford, Wheeler, & Koohmaraie, 1997; Yacowitz, Davis, & Jones, 1978). However, these techniques are destructive, time consuming, and unsuitable for on-line application. The development of fast, non-destructive, accurate, and on-line/at-line techniques is desired. Near infrared (NIR) spectroscopy could form the basis for such techniques due to the speed, ease of use, and less interferences from moisture or color of meat samples.

Over the years, NIR spectroscopy has been developed and applied considerably in quality management of beef meat products (Mitsumoto, Maeda, Mitsuhashi, & Ozawa, 1991; Park, Chen, Hruschka, Shackleford, &

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0309-1740/03/$ - see front matter Published by Elsevier Ltd.
doi:10.1016/S0309-1740(02)00328-5

Koohmaraie, 1998; Rodbotten, Mevik, & Hildrum, 2001; Venel, Mullen, Downey, & Troy, 2001). Common applications have included not only the quantitative prediction of chemical, textural, and sensory properties of beef meat (Mitsumoto et al., 1991; Park et al., 1998; Rodbotten et al., 2001; Venel et al., 2001), but also the classification of beef into tender and tough classes (Park et al., 1998; Rodbotten et al., 2001). Although these studies indicate that NIR spectroscopy is feasible and promising in the quality control of beef products, the results, especially on meat tenderness prediction, have been inconsistent. Also, color is one of the most important meat characteristics that consumers consider before making a decision to buy. Few studies are available in the prediction of color characteristics from NIR measurement.

The objective of this study was to examine the feasibility of visible/NIR spectroscopy for the prediction of texture, color, and sensory attributes during the aging of beef meats. In addition, we present a comparison in the classification of tender and tough beef steaks into individual classes on the basis of partial least squares (PLS) regression and principal component analysis (PCA) models.

2. Materials and methods

2.1. Meat samples

Between August 2000 and August 2001, strip loins were removed approximately 48 h post slaughter from 24 carcasses. Among them, 10 were Angus heifer carcasses (average live weight = 551.4 kg, backfat = 1.73 cm, ribeye area = 78.3 cm^2, and USDA quality grade = low choice), other 6 and 8 carcasses were Hereford steers which had grazed tall fescue pastures for 135 days infected with wild-type endophyte and non-toxic endophyte (MAXQTM, Pennington Seed, Madison, GA, USA), respectively. Average live weight, backfat, and ribeye area was 428.6 kg, 0.44 cm, 51.7 cm^2, and 467.0 kg, 0.53 cm, and 58.1 cm^2 for steers grazing endophyte and non-toxic endophyte pastures, respectively. USDA quality grades ranged from high standard to low select. For each carcass, six to eight steaks, 2.5 cm thick, were cut from the strip loins, vacuum-packaged, and randomly assigned to aging times of 2, 4, 8, 14, and 21 days at 4 °C. After the appropriate aging time, steaks were removed from packages for visible/NIR and instrumental color measurement. The steaks were then re-packaged with slight vacuum and frozen for subsequent cooking for Warner-Bratzler shear force and sensory analysis.

2.2. Visible/NIR spectroscopic measurement

The steaks were scanned on a NIRSystems 6500 monochromator (NIRSystems, Silver Spring, MD, USA) equipped with a sample transport module and either a quartz-windowed sample cell or a quartz-windowed cylindrical cup. Edges of the steaks were trimmed with a knife to allow the sample to fit into the cells. Reflectance measurements were recorded over the 400–2498 nm wavelength range at 2 nm intervals and 32 scans. The instrument was operated by the software package NIRS3 v.4.10 (Infrasoft International, Inc., Port Matilda, PA, USA). The obtained spectra were imported into Grams/32 by using Grams/32 software (Galactic Industrious Corp., Salem, NH, USA), and subsequently loaded into PLSPlus/IQ package in Grams/32 to perform the exploratory data analysis, namely partial least squares (PLS) regression and principal component analysis (PCA).

2.3. Color measurement

Color was recorded with a Minolta CR-210 colorimeter (Minolta Corp., Ramsey, NJ, USA). The instrument was calibrated against ceramic reference illuminant C prior to use. Three random readings at different locations per sample were taken and averaged. Hunter L (lightness), a (redness), and b (yellowness) were measured. To enhance the fraction of redness relative to those of yellowness and lightness, E^* was calculated using the following modified equation (Liu, Fan, Chen, & Thayer, 2003):

$$E^* = a/b + a/L$$

2.4. Cooking of steaks

Strip steaks were removed from the −30 °C freezer, weighed, thawed overnight in a refrigerator (4 °C). Prior to cooking, steaks were reweighed, and a thermocouple was inserted into the center of each steak avoiding fat/gristle areas and attached to a 12-channel Digisense scanning thermometer for temperature monitoring during cooking. Initial temperature was recorded prior to onset of cooking. Steaks were broiled on Farberware grills to an internal temperature of 71 °C (AMSA, 1995), turning when the first side reached 35–40 °C IT and again, if necessary, to avoid excessive browning. Cooking time, final temperature, and cooked weight were recorded. The cooked steaks were placed on trays, covered with plastic wrap, and cooled for 24 h at 4 °C before cutting for Warner–Bratzler shears. For sensory analysis, steaks were covered with aluminum foil and tempered for 5–10 min prior to trimming the browned/fat edges and cutting panelist samples.

2.5. Warner–Bratzler shear force measurement

Cores, 1.27-cm diameter, were removed parallel to the longitudinal orientation of muscle fibers. Each core was sheared perpendicular to the longitudinal orientation of the muscle fibers with a Warner-Bratzler shear attachment (1-mm thick) using a Texture Analyser TA-XT2 (Texture Technologies Corp., Scarsdale, NY, USA) fitted with a 25 kg load cell. Test speed was 4.2 mm/sec, travel distance was 55 mm, and calibration distance was 1-mm. Maximum force measured to cut the core was expressed as kilogram (kg). For each steak, six cores were taken and the average of the maximum forces was used for data analysis.

2.6. Sensory evaluation

Steaks were cut into 2.54×1.27×1.27 pieces using a steak guide. Scores for visual doneness of the interior meat were recorded by experienced lab personnel using the "Beef Steak Color Guide" (AMSA, 1995). Two diced pieces per sample per panelist were placed in individual warmed 6-oz Pyrex glass cups that were inserted into styrofoam bowls, covered with plastic lids, and tempered for 5-min prior to serving to the panelists.

Sensory analysis was performed by a seven-member trained descriptive panel. In 2-h panel sessions (16 h total), panelists evaluated 5–7 steak samples in a monadic presentation 15 min apart. Steaks were assigned to a panel session and sample set, randomized for aging time within animal. Each panelist evaluated two cubes from each sample for juiciness and chewiness on 5-point intensity scales (1 = not at all chewy, juicy to 5 = extremely chewy, juicy) where chewiness was defined as the amount of work to get the sample ready to swallow and juiciness was defined as overall amount of juice/moisture perceived in the mouth.

2.7. Chemometric models

The data analysis was performed in the Grams/32 PLSPlus/IQ package (Version 5.2, Galactic Industrious Corp., Salem, NH, USA). Partial least squares (PLS) regression was used in predicting Warner-Bratzler shear force, color, and sensory properties from visible/NIR spectra, and soft independent modeling of class analogy (SIMCA) of principal component analysis (PCA) was used in classifying beef samples into tender and tough classes. Both PLS and PCA models were developed in 400–1080 nm spectral region and with spectral preprocessing of either multiplicative scatter correction (MSC) + mean center (MC) or MSC + MC + the second (2nd) derivative (Savitzky-Golay derivative function and 11 smoothing points). Full cross-validation was used as the validation method. The predictive accuracy of the PLS models was given by RMSEC (root mean square error of calibration) and R^2 (coefficient of determination), and the performance of the PCA models was reported as the number of samples correctly classified.

3. Results and discussion

3.1. Variations of color, shear values and sensory attributes of beef meats in aging

Table 1 summarizes the variations in color, shear values, and sensory attributes of beef steaks in the aging process. Hunter color analysis suggested that the steaks generally were lighter (higher *L*), redder (higher *a*), and more yellow (higher *b*) as aging time increased. Warner-Bratzler shear force and sensory chewiness decreased, as expected, with the aging. However, sensory juiciness changed very little, in agreement with earlier reports (Hildrum et al., 1995; Naes & Hildrum, 1997). In general, E^* decreased with time, probably indicating the loss of meat redness (Liu & Chen, 2000; Liu et al., 2003).

3.2. Visible/NIR spectra of beef meats in aging

Fig. 1 shows the average visible/NIR reflectance spectra of the beef steaks measured at 2, 8, and 14 days post mortem. There are four broad bands at approximately

Table 1
Hunter color attributes, Warner–Bratzler shear force and sensory traits of beef steaks across aging time

Steak characteristics	Aging time (day)					Mean[f]	S.D.
	2[a]	4[b]	8[c]	14[d]	21[e]		
Uncooked							
L	37.13	37.63	38.60	38.48	38.52	38.07	2.74
a	16.22	17.26	17.73	16.86	18.47	17.27	4.25
b	6.48	7.19	7.83	7.92	8.15	7.50	2.43
E^*	3.10	2.95	2.80	2.59	2.82	2.85	0.52
Cooked							
Shear force, kg	7.38	5.85	5.36	4.79	3.68	5.46	2.12
Sensory							
Chewiness[g]	3.50	3.43	3.21	3.18	2.70	3.19	0.57
Juiciness[h]	2.29	2.36	2.28	2.44	2.36	2.37	0.25

[a] Average of 22 measurements (Hunter values and Warner–Bratzler shear force) and 10 measurements (sensory) at 2 days post mortem.
[b] Average of 24 measurements (Hunter values and Warner–Bratzler shear force) and 10 measurements (sensory) measurements at 4 days post mortem.
[c] Average of 24 measurements (Hunter values and Warner–Bratzler shear force) and 10 measurements (sensory) measurements at 8 days post mortem.
[d] Average of 24 measurements (Hunter values and Warner–Bratzler shear force) and 24 measurements (sensory) measurements at 14 days post mortem.
[e] Average of 19 measurements (Hunter values and Warner–Bratzler shear force) and 10 measurements (sensory) measurements at 21 days post mortem.
[f] Average of all measurements at 2, 4, 8, 14, and 21 days post mortem.
[g] 1 = Not at all chewy, 5 = extremely chewy.
[h] 1 = Not at all juicy, 5 = extremely juicy.

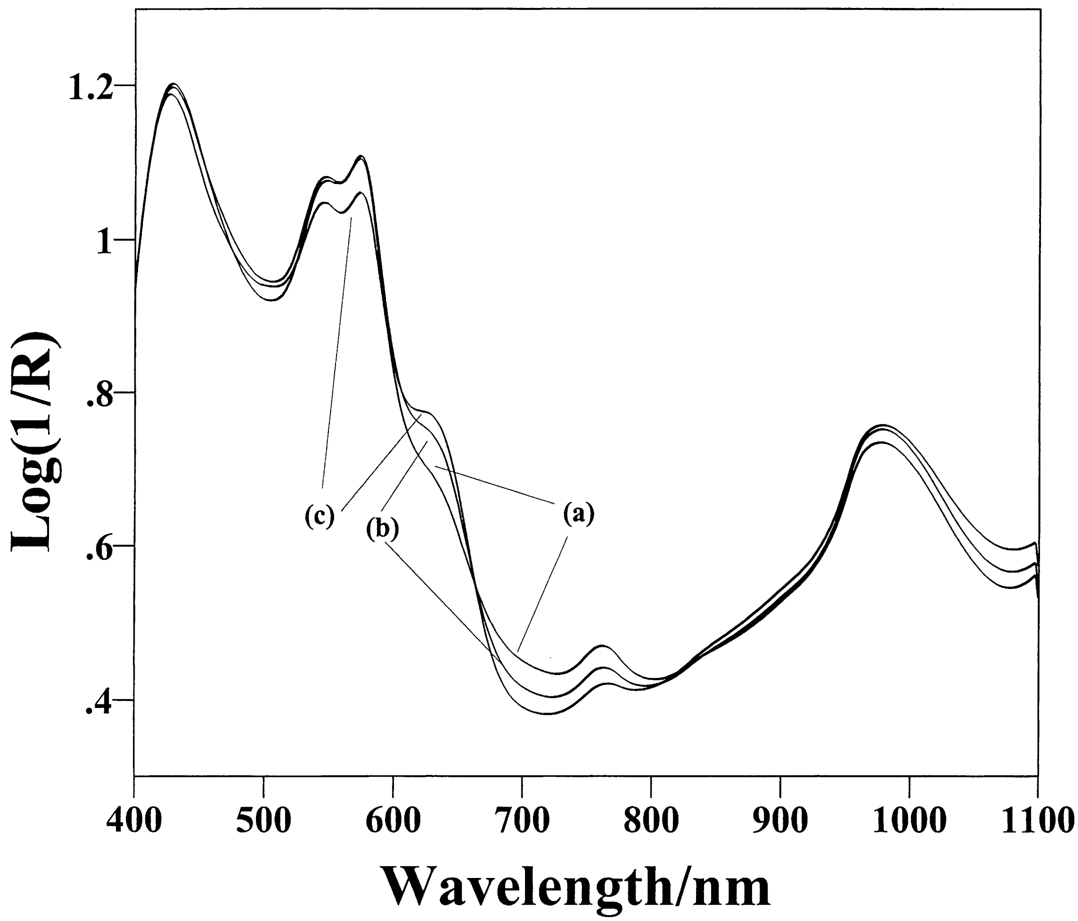

Fig. 1. Average visible/NIR reflectance spectra of beef meats during the aging at 2 days (a), 8 days (b), and 14 days (c) post mortem in the 400–1100 nm region.

430, 545, 575, and 635 nm in visible region (400–750 nm), and two broad bands around 760 and 980 nm in NIR region (750–1100 nm). The spectral features in the visible region are very similar to those of chicken meat reported earlier (Liu & Chen, 2000; Liu, Chen, & Ozaki, 2000a, 2000b). This is because both beef and chicken contain the myoglobin protein, which is the primary heme pigment responsible for color of meat (Francis & Clydesdale, 1975; Kinsman et al., 1994; Lawrie, 1985). Previous systematic study on a variety of chicken muscles has concluded that the bands at 430 and 635 nm arise mainly from deoxymyoglobin and sulfmyoglobin, respectively, and the 545 and 575 nm bands result from oxymyoglobin species in different molecular environment of heme vibrations (Liu & Chen, 2000).

With increasing aging time, peak intensity increase of the broad band near 635 nm and the peak intensity reduction of two broad bands around 545 nm and 575 nm were clearly observed. The spectral intensity variations of the peaks at 545, 575, and 635 nm likely suggested a dynamic conversion and degradation for a number of myoglobin derivatives (Liu & Chen, 2000, 2001; Liu et al., 2003).

A weak NIR band at 760 nm is from the third overtone of O-H vibration, while the strong and broad band at 980 nm is most likely due to water (Osborne, Fearn, & Hindle, 1993). Fig. 1 shows that the intensity of the 760 nm band decreased and that of the 980 nm increased with the aging.

Unlike the obvious spectral intensity increase or decrease in visible region, there were only minor NIR spectral intensity variations. Hence, visible spectroscopy seems to be useful for the characterization of meat colors. However, NIR spectra might provide the complementary information to visible spectra, such as the change in tenderization (due to proteolysis and denaturation of proteins during the storage) other than the discoloration in meats.

Actually, relatively large variations in visible/NIR spectra were observed among the individual beef samples (not shown). Despite these variations, it is possible to examine semi-qualitatively the information between spectrum and related color/eating quality attributes. As an example, Fig. 2 shows the difference spectrum between two spectra of beef steaks having close Warner–Bratzler shear force values but with large differences in

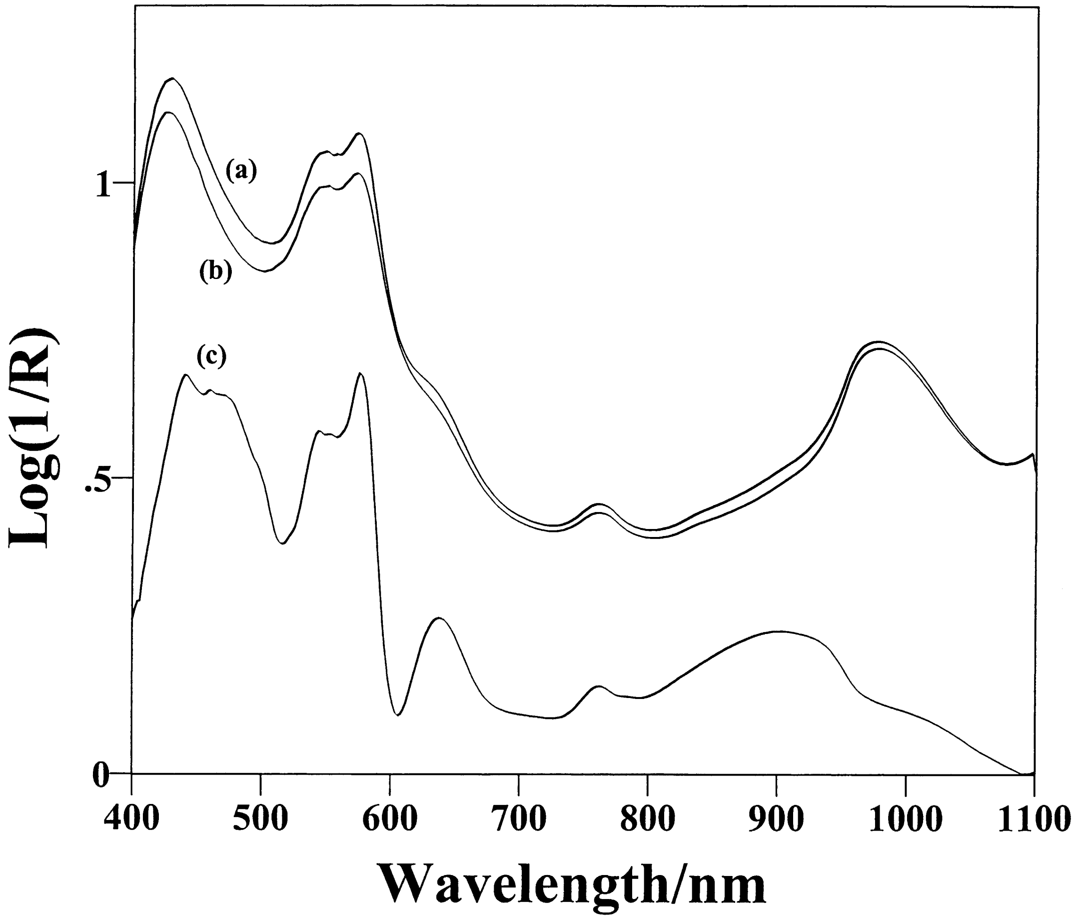

Fig. 2. Visible/NIR reflectance spectra of (a) beef meat A (L = 38.30, a = 15.96, b = 6.21, and Warner–Bratzler shear force = 5.86 kg), (b) beef meat B (L = 40.54, a = 12.72, b = 4.93, and Warner–Bratzler shear force = 5.81 kg), and (c) difference spectrum by subtracting spectrum (b) from spectrum (a). Difference spectrum was multiplied by 10 to fit the y-axis scale.

Hunter values. Most notable features are broad bands centered at 440, 475, 545, 575, 635, and 910 nm. The 440 and 545 nm (together with 575 nm) bands have been identified as deoxymyoglobin and oxymyoglobin, whose color is described as purplish-red and cherry-red, respectively; while the 475 and 635 nm bands have been assigned to metmyoglobin and sulfmyoglobin species which are brownish-red and green in color (Liu & Chen, 2000; Liu et al., 2000b). Besides the difference in color characteristics, two samples definitely varied in many other factors, and one of them could be represented by the band around 910 nm. The 910 nm band might indicate a contribution of proteins (Venel et al., 2001).

3.3. *Prediction of Warner–Bratzler shear force from visible/NIR spectra*

Partial least squares (PLS) regression models for Warner–Bratzler shear force were developed using different data pre-treatments and the aging condition. The results are summarized in Table 2. With the data pre-treatment of second derivative, the models for 14 and 21 days post mortem were improved greatly. Models for 2, 4, and 8 days post mortem remained nearly unaffected; whereas, models for the all-sample set became much poorer. Results indicated, at least, that the visible/NIR spectral information of steaks in 14 and 21 days differs from those in 2, 4, and 8 days post mortem. This observation is consistent with the result by Liu and Chen (2000) who reported two clusters, with one representing the storage process from 2 to 9 days and another from 10 to 18 days, when principal component analysis (PCA) was applied to visible/NIR spectra of chicken meats in cold storage.

Examination of the measured Warner–Bratzler shear force data suggested that the number of tough steaks decreased from 2 to 21 days aging, if the boundary was set to 6.0 kg. There were 13 tough steaks in 22 samples (59.1%) after 2 days aging, 12 in 24 samples (50%) after 4 days aging, 5 in 24 samples (20.8%) after 8 days aging, 2 in 24 samples (8.3%) after 14 days aging, and 1 in 19 samples (5.3%) after 21 days aging. Note that the samples with the aging times of 2, 4, and 8 days had a higher percentage of tough meat (>20.8%) than those aged 14 and 21 days (<10%). The decrease in relative fraction of tough meat samples suggested some chemical and

Table 2
Prediction of Warner–Bratzler shear force by visible/NIR spectroscopy

	No. of samples	Mean±S.D.[a] (kg)	Spectral pretreatment[b]	No. of optimal factors[c]	RMSEC[d] (kg)	R^{2e}
2 Days	22	7.38±2.28	MSC+MC	2	1.84	0.41
			MSC+MC+2nd	2	1.72	0.48
4 Days	24	5.85±2.06	MSC+MC	2	1.40	0.64
			MSC+MC+2nd	3	1.22	0.69
8 Days	24	5.36±1.70	MSC+MC	2	1.57	0.22
			MSC+MC+2nd	2	1.61	0.18
14 Days	24	4.79±1.47	MSC+MC	2	1.41	0.17
			MSC+MC+2nd	3	0.84	0.72
21 Days	19	3.68±1.11	MSC+MC	3	1.06	0.24
			MSC+MC+2nd	2	0.81	0.56
All	113	5.46±2.12	MSC+MC	8	1.57	0.49
			MSC+MC+2nd	2	1.91	0.20

[a] Standard deviation (S.D.).
[b] Multiplicative scatter correction (MSC), mean center (MC), and the second derivative (2nd).
[c] Number of factors used to perform the calibration equation model.
[d] Root mean square error of calibration (RMSEC).
[e] Coefficient of determination in calibration.

physical changes during the aging process. Probably, the differences in relative amount of tough meat might have a great effect on PLS model developments for subgrouped data sets. So, the observation validated the above statement resulting from spectra.

The optimal model of the determination of Warner-Bratzler shear force for all samples gives a coefficient of determination (R^2) of 0.49 and root mean square error of calibration (RMSEC) of 1.57 kg. Hence the samples were grouped into different categories on the basis of aging time, models for 4, 14, and 21 days post mortem were improved, while that for 8 days post mortem showed less accuracy with much lower R^2. Therefore, as a compromise, the model for all samples is still acceptable for the beef steaks at different aging days. This is a moderate correlation between the measured and the predicted shear force values. Venel et al. (2001) reported that the NIR prediction of tenderness and other quality attributes of beef at 14 days post mortem was improved when the sample set was segregated according to animal grade, sex, ultimate PH or day of bone out. Undoubtedly, further work is necessary to improve the visible/NIR application for meat industry.

The obtained result is similar to previous reports on the prediction of Warner–Bratzler shear force of beef from NIR spectra (Mitsumoto et al., 1991; Park et al., 1998; Rodbotten et al., 2001; Venel et al., 2001). However, direct comparison of prediction results is difficult due to several reasons. For example, condition of meat samples varied in the state of fresh, aging, frozen and thawed, Warner-Bratzler shear force instruments were different, and the spectra were measured in reflectance/transmittance mode.

In addition, Table 2 shows that the standard deviation (SD) decreased with the aging, indicating that tender meat was less variable than tough meats or that as meat ages, there is less variation in condition of muscle.

3.4. Classification of tender and tough beef steaks from visible/NIR spectra

Fig. 3 shows a plot of the predicted and measured Warner-Bratzler shear force values from the optimal PLS model for all 113 samples. Beef steaks were classified into two groups according to predicted Warner-Bratzler shear force values (the boundary was set to 6.0 kg). The classification is summarized in Table 3. Of the 82 meat samples measured with Warner-Bratzler shear force values less that 6.0 kg, 70 samples (85.4%) were predicted to have Warner-Bratzler shear force values less than 6.0 kg. Of the 31 meat samples measured to have Warner-Bratzler shear force values greater than 6.0 kg, 80.6% were predicted to have Warner-Bratzler shear force values greater than 6.0 kg. Therefore, the overall accuracy of the classification was 83.0%.

Alternatively, the application of principal component analysis (PCA) was attempted (Galactic, 1996). Eighty-two spectra representing the tender steaks (measured Warner-Bratzler shear force less than 6.0 kg) and 31 spectra representing the tough steaks (measured Warner-Bratzler shear force greater than 6.0 kg) were used for calibration model development. Classification models were developed using two classes (tender and tough) and with MSC+MC spectral pretreatment, based on SIMCA (Soft Independent Modeling of Class Analogy) of principal component analysis (PCA) with a Mahalanobis distance (Galactic, 1996). For each of the two classes, the optimal number of factors was suggested to be 14 or 11. By applying two SIMCA classes (tender

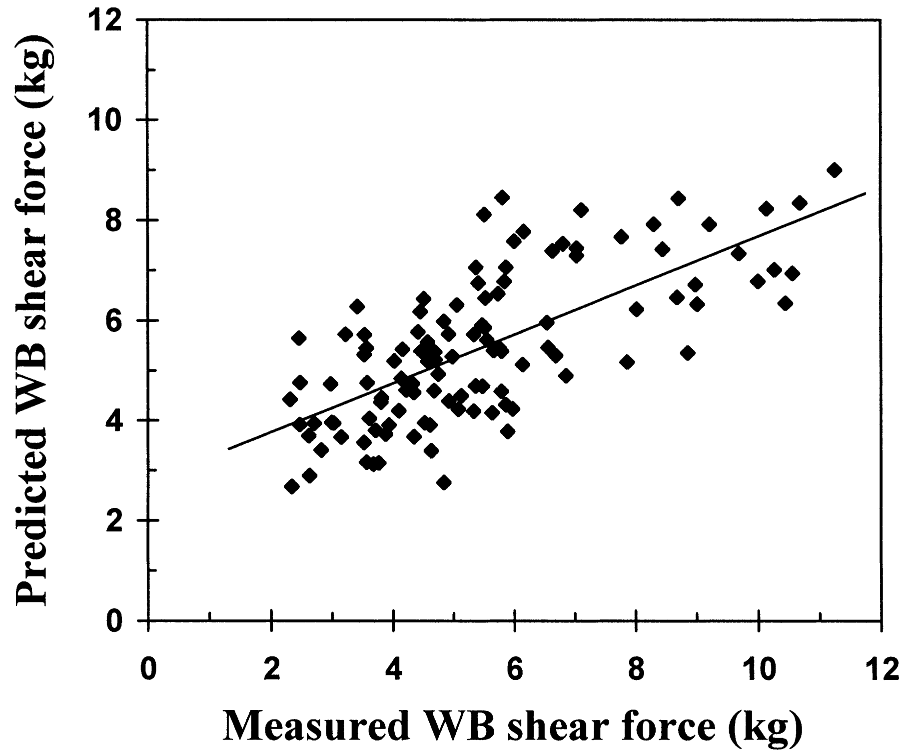

Fig. 3. Correlation plot of measured vs visible/NIR predicted Warner–Bratzler (WB) shear force.

Table 3
Two-group classification of "tender and tough" beef steaks from visible/NIR spectroscopy based on predicted/measured Warner–Bratzler shear force values

Models	Spectral pretreatment[a]	% Correct classification of tender class[b]	% Correct classification of tough class[c]	Average[d] (%)
PLS	MC + MSC	85.4	80.6	83.0
SIMCA/PCA	MC + MSC	98.8	93.5	96.1

[a] Multiplicative scatter correction (MSC) and mean center (MC).
[b] Tender meats with predicted/measured Warner–Bratzler shear force less than 6.0 kg.
[c] Tough meats with predicted/measured Warner–Bratzler shear force greater than 6.0 kg.
[d] Mean of% correct classification for tender and tough classes.

and tough) to all 113 samples and employing the class assignment rule of lower Mahalanobis distance, the sample was identified as the group being modeled, i.e. either tender or tough. The obtained classification result from SIMCA/PCA model is also shown in Table 3 and, obviously, is better than the results from PLS models presented here and reported in the previous study (Park et al., 1998; Rodbotten et al., 2001), with a correct classification of 96.1%. The SIMCA/PCA model might be interesting and promising, as it only included the information of measured Warner–Bratzler shear force information and ignored other factors such as the aging process.

3.5. Prediction of color characteristics from visible/NIR spectra

PLS calibration models were developed on Hunter *a*, *b*, *L*, and *E** sets respectively, and the results are shown in Table 4. Generally, R^2 for models predicting *a* (redness), *b* (yellowness) and *E** (fraction of redness relative to yellowness and lightness) are quite high, and that for the model predicting *L* (lightness) is relatively low. This might be reasonable and expected, as meat components absorbing in the 400–1080 nm region are mostly the myoglobin derivatives which have different colors and, in turn, these colors determine the magnitude of *a* and *b* value. No improved models were observed responding to further 2nd derivative pretreatment (results not shown).

3.6. Prediction of sensory characteristics from visible/NIR spectra

Table 4 also shows the calibration statistics for sensory chewiness and juiciness, respectively. Spectral data pretreatments with MSC + MC + 2nd derivative gave better models than the combination of MSC + MC. The R^2 and RMSEC for optimal models predicting chewiness and juiciness are 0.58 and 0.38, and 0.50 and 0.18, respectively. Lower RMSEC for juiciness possibly is due to the small range of sensory values (Hildrum et al., 1995). That is, all steaks were relatively juicy.

Table 4
Prediction of Hunter color and sensory characteristics of beef steaks by visible/NIR spectroscopy

	Mean ± S.D.	Spectral pretreatment[a]	No. of optimal factors[b]	RMSEC[c]	R^{2d}
Hunter color					
a	17.27 ± 4.25[e]	MSC + MC	5	1.38	0.90
b	7.50 ± 2.43[e]	MSC + MC	5	1.16	0.78
L	38.07 ± 2.74[e]	MSC + MC	6	1.90	0.55
*E**	2.85 ± 0.52[e]	MSC + MC	5	0.24	0.79
Sensory					
Chewiness	3.19 ± 0.57[f]	MSC + MC + 2nd	4	0.38	0.58
Juiciness	2.37 ± 0.25[f]	MSC + MC + 2nd	4	0.18	0.50

[a] Multiplicative scatter correction (MSC), mean center (MC), and the second derivative (2nd).
[b] Number of factors used to perform the calibration equation model.
[c] Root mean square error of calibration (RMSEC).
[d] Coefficient of determination in calibration.
[e] Mean ± standard deviation (S.D.) for 113 samples.
[f] Mean ± standard deviation (S.D.) for 64 samples.

The obtained sensory results are better than the results reported by Hildrum et al. (1995). Those authors observed that the multivariate correlation coefficients (*R*) were 0.74, 0.70, and 0.61 for sensory hardness, tenderness, and juiciness, based on the sensory intensity scale from 1 to 10.

As shown in Tables 2 and 4, the R^2 for shear values, chewiness, and juiciness were lower than those for Hunter *a*, *b*, and *E** values. This might be explained by the fact that the samples for shear values and sensory analysis were frozen, thawed and cooked. To prompt the application of visible/NIR spectroscopy further for this purpose, it is necessary to obtain more knowledge about the relationship between chemical/physical properties of meats and the visible/NIR spectra.

4. Conclusions

This study indicates that visible/NIR spectroscopy has the feasibility to predict shear values, color and sensory characteristics of beef steaks during the aging process. Contrary to previous studies, predictive accuracy of shear value was not always improved when the samples were subgrouped based on aging days. As expected, the predictive models of Hunter *a*, *b*, and *E** had better accuracies than those of shear values, chewiness and juiciness, because the information of shear value, chewiness and juiciness were extracted from cooked beef steaks. From visible/NIR predicted tenderness values in PLS model, beef samples were classified into tender and tough classes with a correct classification of 83%. As an alternative, a model based on SIMCA/PCA of measured tenderness was attempted. It showed great promise in the classification of tender and tough meats with over 96% success.

Acknowledgements

The authors wish to express their sincere thanks to Ms. Elizabeth M. Savage, food technologist, Russell Research Center, ARS, for assisting in analyses and sensory evaluation.

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